Transport and reaction coefficients for electrons in Ar, H2, N2, O2, and dry air calculated using the cross sections in uploaded file "ELECTRON_CS.pdf".

Electron Transport Data.

GASES COMPILED: N2, Ar, H2, O2, and dry air.
last revised 5/7/98

This URL is ftp://jila.colorado.edu/collision_data/eletrans.txt
Please inform us if you have difficulties downloading this file.
It is intended to fit within a 120 column data file.

These calculations were made using cross section sets listed in the URL ftp://jila.colorado.edu/collision_data/electron.txt and using BACKPRO. The more recent calculations were made using version BKP5C. BACKPRO is described in Frost and Phelps, Phys. Rev. 127, 1621 (1962) and Engelhardt and Phelps, Phys. Rev. 131, 2115 (1963). For details see P. E. Luft, JILA Information Center Report No. 14, Oct. 30, 1975.

WE MAKE NO CLAIMS FOR THESE TRANSPORT AND REACTION COEFFICIENTS BEYOND THOSE STATED IN THE PAPERS WHERE THEY ARE PUBLISHED OR CITED. IN MOST CASES THESE COEFFICIENTS ARE CALCULATED FROM CROSS SECTIONS WERE ASSEMBLED IN THE 1970'S AND 1980'S. IN ONLY A FEW CASES HAVE THEY BEEN MODIFIED OR TESTED SINCE THAT TIME. I DO NOT PLAN ANY UPDATES. ADDITIONS HAVE BEEN MADE WHEN CROSS SECTIONS HAVE BEEN ASSEMBLED FOR OTHER PURPOSES. SINCE THE JILA INFORMATION CENTER WAS CLOSED, THERE IS NO ONE THERE TO HELP YOU. OPINIONS EXPRESSED ARE THOSE OF A. V. PHELPS AND DO NOT IMPLY JILA OR NIST APPROVAL.

GENERAL WARNING TO GAS DISCHARGE MODELERS:
IF AUTHORS DO NOT EXPLICITLY STATE THAT THERE IS AGREEMENT BETWEEN A) IONIZATION, EXCITATION, ATTACHMMENT (IF APPLICABLE), AND TRANSPORT COEFFICIENTS CALCULATED USING THEIR CROSS SECTIONS AND B) RELIABLE EXPERIMENTAL MEASUREMENTS OF THESE COEFFICIENTS, YOU SHOULD BE VERY SKEPTICAL OF ALL OF THEIR CROSS SECTIONS AND OF ELECTRON TRANSPORT AND REACTION COEFFICIENT RESULTS DERIVED FROM THEM. AGREEMENT WITH SWARM EXPERIMENTS SUCH AS IONIZATION COEFFICIENT, DRIFT VELOCITY, THE RATIO OF THE TRANSVERSE AND LOGITUDINAL DIFFUSION COEFFICIENT TO MOBILITY, ATTACHMENT COEFFICIENTS, AND EXCITATION COEFFICIENTS ARE CRICIAL EVIDENCE OF A RELIABLE SET INPUT DATA FOR MODELING. FOR EACH GAS IN THIS FILE WE HAVE SUMMARIZED OUR TESTS OF THE CALCULATED COEFFICIENTS AGAINST EXPERIMENTAL SWARM DATA.

NITROGEN ELECTRON TRANSPORT AND REACTION COEFFICIENTS

From Phelps and Pitchford, JILA Infromation Center Report # 26, JILA, Univ. of Colorado, May 1 1985. (unpublished). This report tabulates data presented in Phelps and Pitchford, Phys. Rev. A 31, 2932 (1985).

These calculations were made using cross section set listed in file ELECTRON.TXT in directory ELECTRON_CROSS at anonymous ftp site jila.colorado.edu and using BACKPRO version BKP5C. BACKPRO is described in Frost and Phelps, Phys. Rev. 127, 1621 (1962) and Engelhardt and Phelps, Phys. Rev. 131, 2115 (1963). For details see JILA Information Center Report No. 14, Oct. 30, 1975. Some more recent changes are discussed in Yoshida, Phelps, and Pitchford, Phys. Rev. A 27, 2858 (1983).

Low E/n Electron Transport Coefficients Calculated Using Two-Term Approximation.**

E/n (1 Td = 10^-21 Vm^2)	.1	.2	.5	1	2	5	10	20	50	70
w (m/s)	2407	2865	3475	4450	6230	11120	17870	30020	62728	81653
D/mu (eV)	.0417	.0726	.1628	.291	.488	.767	.984	1.174	1.383	1.551
<energy> (eV)	.0574	.0939	.202	.368	.594	.832	.958	1.038	1.154	1.409
num/n (m^3/s)	7.319-15	1.239-14	2.53E-14	3.95E-14	5.65E-14	7.91E-14	9.84E-14	1.17E-13	1.40E-13	1.51E-13
nuu (m^3/s)	1.51E-17	1.22E-17	1.27E-17	1.68E-17	2.69E-17	7.5E-17	1.87E-16	5.23E-16	2.31E-15	3.75E-15
(EPL-EPG) (eV-m^3/s)	2.4E-19	5.54E-19	1.2E-18	2.04E-18	3.16E-18	4.44E-18	5.24E-18	5.9E-18	7.26E-18	9.72E-18
EN. BALANCE (%) (Ref. 4)	.004	.017	.126	.224	.65	.63	.98	.96	3.3	2.6
SUM VIB. QUANT (m^3/s)	2.7E-21	6.55E-20	1.84E-18	7.73E-18	2.76E-17	1.58E-16	5.53E-16	1.93E-15	9.98E-15	1.74E-14
C+E EXCT. (m^3/s)									1.12E-19	3.82E-18
SUM TRIPLET (m^3/s)									2.65E-18	4.02E-17
alpha(C+E)/n (m^2)									1.78E-24	4.68E-23
alpha(sum trip.)/n(m^2)									4.23E-23	4.92E-22
alpha(ioniz.)/n (m^2)									4.29E-28	9.53E-26

GAS HEATING CALC.*

	.1	.2	.5	1	2	5	10	20	50	70
ELASTIC & ROT HEAT (%)	99.7	96.6	69.1	49.0	35.3	16.7	8.65	4.74	2.52	2.07
VIB. ENERGY (%)	.326	3.32	30.8	50.5	64.5	82.6	90.0	93.6	92.6	88.8
ION. ENERGY (%)									1.437E-5	.002
ELECT. EX. HEAT (%)									.769	6.77
VIB. COOLING (%)				2.87E-9	7.74E-5	.026	.161	.432	1.00	1.20
NET FAST HEAT. (%)	99.7	96.6	69.1	49.0	35.3	16.7	8.49	4.30	2.29	7.64

Rate Coefficients (m^3/s) for Individual Excitation Processes

PROCESS E/n(Td)	.1	.2	.5	1	2	5	10	20	50	70
RES ROT	0	0	7.02E-20	7.09E-18	6.21E-17	2.44E-16	5.11E-16	1.13E-15	3.6E-15	5.45E-15
V-1	2.71-21	6.55E-20	1.84E-18	7.73E-18	2.76E-17	1.50E-16	4.23E-16	9.91E-16	2.57E-15	3.52E-15
V-2				3.57E-26	2.69E-21	3.51E-18	5.04E-17	2.73E-16	1.21E-15	1.82E-15
V-3					2.9E-24	1.89E-19	9.45E-18	1.05E-16	7.52E-16	1.21E-15
V-4						2.46E-22	1.97E-19	1.31E-17	2.97E-16	6.01E-16
V-5						2.36E-24	3.42E-20	5.36E-18	1.82E-16	4.1E-16
V-6							8.97E-23	3.51E-19	7.33E-17	2.2716
V-7							1.62E-24	3.13E-20	2.12E-17	8.44E-17
V-8								1.38E-21	5.7E-18	2.91E-17
A3SIG									8.71E-20	1.13E-18
A3SIG									2.8E-19	3.92E-18
B3PI									1.18E-18	1.64E-17
W3DEL									6.59E-19	9.61E-18
A3SIG									1.75E-19	2.78E-18
B"3SIG									1.53E-19	2.5E-18
A"1SIG									1.13E-19	1.91E-18
A1PI									2.36E-19	4.1E-18
W1DEL									1.4E-19	2.5E-18
C3PI									1.07E-19	3.69E-18
E3SIG									4.79E-21	1.32E-19
A"1SIG									9.21E-22	4.18E-20
SUM SINGLET									3.6E-21	2.36E-19
TOTAL IONIZATION									2.69E-23	7.78E-21

Higher E/n Electron Transport Coefficients Calculated Using Two-Term Approximation.**

E/n (Td-10^-21 Vm^2)	100	150	200	300	500	1000	1500	2000	3000
w (m/s)	107300	148390	187380	260960	388000	643000	855000	1050000	1410000
D/mu (eV)	2.02	2.96	3.74	4.86	6.67	1O.76	15	19.64	30.7
<energy>	2.24	3.81	5.03	6.73	9.41	15.72	22.4	29.8	47.1
num/n (m^3/s)	1.64E-13	1.78E-13	1.88E-13	2.02E-13	2.27E-13	2.73E-13	3.O8E-13	3.35E-13	3.74E-13
nuu/n (m^3/s)	5.37E-15	7.58E-15	1.01E-14	1.62E-14	2.92E-14	5.99E-14	8.57E-14	1.07E-13	1.38E-13
(EPL-EPG) (eV-m^3/s)	1.70E-17	3.07E-17	4.2E-17	5.96E-17	9.13E-17	1.77E-16	2.75E-16	3.83E-16	6.31E-16
CALC. EN. BALANCE (%)	1.33	.59	.29	.63	.59	.156	.27	.46	.17

SUM VIB QUANT (m^3/s)	2.58E-14	2.90E-14	2.71E-14	2.21E-14	1.59E-14	9.581-15	7.29E-15	6.70E-15	4.73E-15
G+E (m^3/s)	4.92E-17	3.13E-16	7.54E-16	1.76E-15	3.43E-15	5.12E-15	5.23E-15	4.92E-15	4.16E-15
SUM TRIP (m^3/s)	2.85E-16	1.18E-15	2.34E-15	4.63E-15	8.11E-15	1.15E-14	1.17E-14	1.1OE-14	9.38E-15

alpha(C+E)/n (m^2)	4.58E-22	2.11E-21	4.03E-21	6.75E-21	8.85E-21	7.95E-21	6.12E-21	4.69E-21	2.95E-21
alpha(trip1et)/n (m^2)	2.65E-21	7.93E-21	1.25E-20	1.77E-20	2.09E-20	1.78E-20	1.37E-20	1.05E-20	6.66E-21
alphai/n (m^2)	3.69E-24	6.93E-23	2.86E-22	1.23E-21	4.70E-21	1.58E-20	2.54E-20	3.23E-20	3.98E-20

GAS HEATING CALC.*

ELASTIC & ROT. HEAT (%)	1.51	.82	.479	.216	.087	.034	.024	.01	.015
VIB. ENERGY (%)	70.0	37.8	21.0	8.20	2.3	.433	.165	.092	.032
IONIZ. ENERGY (%)	.065	.896	2.95	9.18	23.4	49.4	64.2	73.2	83.1
ELECT. EX. HEAT (%)	27.1	59.1	75.3	81.6	73.4	49.8	35.9	27.1	17.0
VIB. COO1ING (%)	1.1O	.654	.377	.151	.043	.007	.002	.001	5.6E-4
NET FAST HEATING (%)	27.6	59.2	75.4	81.7	73.5	49.9	36.0	27.1	17.1

Rate Coefficients (m^3/s) for Individual Excitation Processes

EXCITATION PROCESS \ E/n(Td)	100	150	200	300	500	1000	1500	2000	3000
RES. ROT.	7.25E-15	7.59E-15	6.88E-15	5.48E-15	3.9E-15	2.24E-15	1.68E-15	1.39E-15	9.55E-16
V-1	4.32E-15	4.34E-15	3.93E-15	3.28E-15	2.69E-15	1.98E-15	1.78E-15	1.45E-15	1.12E-15
V-2	2.36E-15	2.38E-15	2.12E-15	1.63E-15	1.08E-15	6.16E-16	5.36E-16	5.54E-16	3.81E-16
V-3	1.61E-15	1.63E-15	1.44E-15	1.10E-15	7.66E-16	4.37E-16	1.77E-16	2.08E-16	1.43E-16
V-4	9.25E-16	1.03E-15	9.43E-16	7.46E-16	4.92E-16	2.82E-16	2.14E-16	8.71E-17	6.E-17
V-5	6.83E-16	8.06E-16	7.61E-16	6.22E-16	4.59E-16	2.65E-16	2.38E-16	1.58E-16	1.08E-16
V-6	4.6E-16	6.13E-16	6.11E-16	5.25E-16	4.07E-16	2.36E-16	1.39E-16	2.82E-16	1.94E-16
V-7	2.02E-16	3.01E-16	3.14E-16	2.79E-16	1.91E-16	1.12E-16	8.85E-17	5.24E-17	3.6E-17
V-8	8.12E-17	1.33E-16	1.44E-16	1.32E-16	8.49E-17	5.02E-17	5.1E-17	4.06E-17	2.8E-17
A3SIG	6.79E-18	2.34E-17	4.18E-17	7.37E-17	1.20E-16	1.67E-16	1.72E-16	1.65E-16	1.43E-16
A3SIG	2.49E-17	9.03E-17	1.66E-16	3.O1E-16	5.02E-16	7.09E-16	7.35E-16	7.04E-16	6.1E-16
B3PI	1.02E-16	3.5E-16	6.09E-16	1.02E-15	1.53E-15	1.95E-15	1.94E-15	1.83E-15	1.55E-15
W3DEL	6.42E-17	2.49E-16	4.78E-16	9.18E-16	1.58E-15	2.18E-15	2.18E-15	2.04E-15	1.71E-15
A3SIG	1.95E-17	7.66E-17	1.47E-16	2.8E-16	4.84E-16	7.02E-16	7.34E-16	7.06E-16	6.16E-16
B'3SIG	1.82E-17	7.44E-17	1.45E-16	2.76E-16	4.66E-16	6.49E-16	6.74E-16	6.54E-16	5.83E-16
A'1SIG	1.43E-17	5.93E-17	1.16E-16	2.2E-16	3.66E-16	5.03E-16	5.33E-16	5.39E-16	5.35E-16
A1PI	3.17E-17	1.41E-16	2.96E-16	6.4E-16	1.30E-15	2.34E-15	2.8E-15	2.97E-15	3.02E-15
W1DEL	1.91E-17	7.86E-17	1.51E-16	2.76E-16	4.39E-16	5.58E-16	5.45E-16	5.08E-16	4.3E-16
C3PI	4.79E-17	3.07E-16	7.42E-16	1.74E-15	3.39E-15	5.05E-15	5.16E-15	4.86E-15	4.11E-15
E3SIG	1.29E-18	6.03E-18	1.23E-17	2.52E-17	4.29E-17	6.5E-17	7.26E-17	6.34E-17	5.49E-17
A"1SIG	7.1E-19	6.26E-18	1.89E-17	5.85E-17	1.53E-16	3.06E-16	3.62E-16	3.79E-16	3.79E-16
SUM SINGLET	5.38E-18	6.47E-17	2.38E-16	9.83E-16	3.85E-15	1.42E-14	2.45E-14	3.31E-14	4.61E-14
TOTAL IONIZATION	3.96E-19	1.03E-17	5.36E-17	3.22E-16	1.82E-15	1.02E-14	2.17E-14	3.39E-14	5.61E-14

** See appendix B of reference [1] for definitions of these gas heating terms. The ionization energy is equal to 1OO[<energy>+ui)ki/(w/n)]. The electronic excitation heating term includes all excitation except rotatonal and vibrational excitation and the ionization energy term.

** Improved Version of BACKPR code (BKP5C). See Ref. [3]. CALCULATIONS OF 04/(07-11)/84

Missing entries generally mean that the quantity was to small to calculate accurately.

It should be noted that the set of transport and reaction coefficients given above has been shown to be consistent with six different sets of experimental transport and reaction coefficients. These are: drift velocity, +- 10% for E/n <+ 2000 Td; characteristic energy or transverse diffusion coefficient over mobility, +- 10% for E/n <= 500 Td; the magnitude of rapid gas heating via relaxation of rotational levels and redistribution of vibrational population following excitation by electrons for E/n < 40 Td; A triplet Sigma excitation coefficient, +- 10% for 50 < E/n < 330 Td; C triplet Pi excitation coefficient, +- 20% for 40 < E/n < 200 Td; and ionization coefficient, +- 10% for 90 < E/n < 1000 Td. Note that experimental ionization coefficient data seriously disagree above about 1000 Td.

[1] A. V. Phelps and L. C. Pitchford, Phys. Rev. 31, 2932 (1985).

[2] L. S. Frost and A. V. Phelps, Phys. Rev. 127, 1621 (1962) and A. G. Engelhardt and A. V. Phelps, Phys. Rev. 131, 2115 (1963). For details see P. E. Luft, JILA Information Center Report No. 14, Oct. 30, 1975.

[3] S. Yoshida, A. V. Phelps, and L. C. Pitchford, Phys. Rev. A 27, 2858 (1983).

ARGON ELECTRON TRANSPORT AND REACTION COEFFICIENTS

This is an unpublished tabulation.

For E/n < 20 Td these are calculation from 03/21/89 using Shapert and Scheibner excitation cross sections for energies below the ionization potential.

FOR E/n >= 20 Td THESE ARE REVISED COEFFICIENTS USING THE REVISED Ar CROSS SECTION SET OF 10/15/97. SEE THE FILE ELECTRON.TXT FOR A DISCUSSION OF THE REVISION. THE CROSS SECTIONS DID NOT CHANGE FOR ENERGIES BELOW 22 eV AND THE CALCULATED EXCITATION AND TRANSPOERT COEFFICIENTS DID NOT CHANGE MORE THAN 1% FOR E/n < 500 Td.

This is not intended to be a complete set of excitation coefficients for Ar. It was developed for use in mixtures where detailed excitation coefficients were not needed, but is consistent with Ar transport and ionization coefficients. Because of our disagreement with a number of sets of calculated ionization coefficients now in use it is important to note that the ionization coefficients listed here do fit experimental data such as that of Kruithof and Penning, Physica 3, 515 (1936) and Kruithof, Physica 7, 519 (1940) to about 10% for E/n <= 1000 Td.

These calculations were made using cross section set listed at the URL
ftp://jila.colorado.edu/electron_cross/elecron.txt
and using BACKPRO version BKP5C. BACKPRO is described in Frost and Phelps, Phys. Rev. 127, 1621 (1962) and Engelhardt and Phelps, Phys. Rev. 131, 2115 (1963). For details see P.E. Luft, JILA Information Center Report No. 14, Oct. 30, 1975.

NOTE THAT THE SPATIAL EXCITATION COEFFICIENTS alphax/n LISTED IMMEDIATELY BELOW FOR Ar 811.5 NM, 810.4 NM, AND 5s+4d ARE CALCULATED USING CROSS SECTIONS THAT HAVE BEEN MULTIPLIED BY 1E-4 AS DESCRIBED IN THE FILE ELECTRON.TXT OF THIS FTP DIRECTORY. ALSO NOTE THAT THE IONIZATION COEFFICIENTS ARE CALCULATED USING

THE FORMULAS FOR SPATIAL IONIZATION GROWTH APPROPRIATE TO A STEADY-STATE-TOWSEND EXPERIMENTS, SUCH AS THOSE OF KRUITHOF, PHYSICA 7, 519 (1940). THE PROCEDURE IS GIVEN IN EQS. (14)-(16) OF A.V. PHELPS AND L.C. PITCHFORD, PHYS. REV. 31, 2932 (1985). paragraph added 9/14/99

1 Td = 10E-21 V m^2 calculations of 10/15/97

			811.5 nm	810.4 nm	5s+3d			avg.	total			
E/n	W	Vconv	alphax/n	alphax/n	alphax/n	DT/u	DL/u	<E>	Num/n	Nuu/n	alphax/n	alphai/n
Td	m/s	m/s	m2	m2	m2	eV	eV	eV	m3/s	m3/s	m2	m2
1	3010	3010				3.98	0.616	2.46	3.84E-14	7.62E-19	NA	NA
1.5	3340	3340				4.81	0.747	3.01	7.9E-14	1.05E-18	NA	NA
2	3580	3580				5.52	0.847	3.47	9.84E-14	1.3E-18	1.07E-28	NA
3	3930	3930				6.75	1.026	4.2	1.34E-13	1.75E-18	1.15E-24	NA
5	5170	5170	6.77E-26			7.77	2.3	5.02	1.7E-13	3.34E-18	1.16E-22	NA
7	7290	7290	1.32E-24			7.6	na	5.24	1.69E-13	6.74E-18	3.48E-22	5.96E-30
10	10540	10540	9.96E-24			7.47	3.48	5.37	1.67E-13	1.42E-17	6.71E-22	1.84E-27
20	20050	20070	1.15E-22	9.21E-24	3.42E-23	7.67	3.59	5.64	1.75E-13	5.24E-17	1.61E-21	1.58E-24
30	28300	28500	2.97E-22	2.32E-23	1.41E-22	7.98	3.58	5.88	1.86E-13	1.07E-16	2.48E-21	1.79E-23
50	43100	44200	7.18E-22	5.55E-23	4.97E-22	8.46	3.49	6.27	2.04E-13	2.55E-16	4.04E-21	1.54E-22
70	56600	59600	1.12E-21	8.9E-23	9.02E-22	8.80	3.35	6.60	2.17E-13	4.52E-16	5.38E-21	4.46E-22
100	75800	82700	1.48E-21	1.26E-22	1.32E-21	8.57	3.18	6.84	2.32E-13	8.88E-16	6.45E-21	9.72E-22
200	134800	157400	2.33E-21	2.49E-22	2.30E-21	8.77	3.04	7.68	2.61E-13	3.08E-15	9.54E-21	3.30E-21
300	190000	229000	2.78E-21	3.37E-22	2.82E-21	8.97	3.21	8.39	2.78E-13	6.37E-15	1.17E-20	5.75E-21
500	294000	366000	3.19E-21	4.44E-22	3.37E-21	9.43	3.88	9.74	2.99E-13	1.56E-14	1.50E-20	1.05E-20
1000	529000	689000	3.22E-21	5.28E-22	3.83E-21	11.0	7.40	13.4	3.32E-13	4.81E-14	1.95E-20	2.08E-20
2000	929000	1290000	2.50E-21	5.08E-22	3.79E-21	16.2	na	22.6	3.78E-13	1.15E-13	2.20E-20	3.44E-20
3000	1260000	1860000	1.88E-21	4.55E-22	3.45E-21	22.8	na	33.4	4.17E-13	1.67E-13	2.14E-21	4.16E-20

An extensive set of cross sections and of transport and excitation coefficients for electrons in Ar is that of V. Peuch and L. Torchin, J. Phys. D 19, 2309 (1986). Note that these authors appear to have omitted the effects of the imprisonment of resonance radiation on cascading from the s and d states. Note that these imprisonment effects may not may not be important compared to quenching and level mixing at their very high gas densities, but could be important for discharges with pressures of a few mTorr to 10's of Torr and dimensions of a few cm. A distrubing feature of these results is the large discrepancy between their theory and the experiments of Tachibana, Phys. Rev. A 34, 1007 (1986) for the excitation of metastable atoms.

A more limited cross section set that is consistent with ionization coefficient measurements is available in the file SIGMALIB.DAT at http://www.sni.net/.
However, one must be careful to get the revised Q's not the set used by Fiala et al (1994).

The very extensive set of cross sections developed by M. Hayashi (unpublished) has been tested against transport data by K. Nanbu and J. Kageyama, J. Phys. D, 47, 1031 (2000). Prof. Hayashi has allowed us to present his cross section in the accompanying file Hayashi.txt

For additional comparisons of experimental and calculated excitation and ionization coefficients for electrons in Ar see Bozin et al, Phys. Rev. E 53, 4007 (1996).

na = not available

HYDROGEN ELECTRON TRANSPORT AND REACTION COEFFICIENTS

These transport and reaction coefficients for electrons in H2 are from JILA Information Center Report No. 27, May (1985).

As discussed in Ref. [1], the transport and ionization coefficients presented here agree with experiment to within 5%.

Calculated using two-term approximation and code BACKPRO [2]. Calculations of 07/16A/84 plus 03/22/85 using cross sections discussed in Buckman and Phelps [1] and tabulated in Report 27 and at URL ftp://jila.colorado.edu/cross_section/electron.txt.

Although some of the entries in this table contain many figures the accuracy of the results is not expected to be better than 5%.

Tgas = 77K. 1 Td = lE-21 V m^2 = 10^-21 V m^2

TEMPORAL GROWTH SOLUTION:

E/N (1 Td=1E-21 V m^2)	.005	.01	.03	.1	.3	1	2	5	10
w(m/s)	178.93	331.03	757.6	1721.8	3626.9	6764.8	8762.9	13067	19048
D/u (eV)	.006945	.0078	.011795	.02116	.03617	.08546	.15916	.32322	.49954
<E> (eV)	.010143	.011022	.015512	.02669	.04579	.109091	.19876	.38812	.59555
vm/n (m3/s)	4.92E-15	5.31E-15	6.97E-15	1.02E-14	1.45E-14	2.60E-14	4.02E-14	6.73E-14	9.23E-14
vu/n (m3/s)	2.94E-18	2.85E-18	4.41E-18	1.19E-17	3.68E-17	8.58E-17	1.15E-16	2.06E-16	3.86E-16
(EPL-EPG)(eV-m3/s)		2.03E-21	1.73E-20	8.16E-20	2.66E-19	1.38E-18	3.98E-18	1.29E-17	2.70E-17
EN. BALANCE (%)	.028	.025	.032	.23	.26	.23	.28	.23	.42

Spatial excitation and ionization coefficients (m2)

	.005	.01	.03	.1	.3	1	2	5	10
SUM VIB QUANT						2.91E-22	4.73E-19	3.00E-17	1.66E-16
SUM TRIPLET									
MAX SUM VUV									
alpha/n VIBRATION						4.31E-26	5.40E-23	2.29E-21	8.73E-21
alpha/n DISSOCIATION									
alpha/n VUV									
alpha/n ION									

FAST GAS HEATING CALCULATIONS [3]:

	.005	.01	.03	.1	.3	1	2	5	10
INPUT ENERGY (eVm3/s)	8.95E-22	3.31E-21	2.27E-20	1.72E-19	1.09E-18	6.76E-18	1.75E-17	6.53E-17	1.90E-16
ELASTIC HEAT (%)		61.17270	76.07357	47.39226	24.44696	20.42928	22.72079	19.71378	14.16947
ROTATION. HEAT (%)		38.43852	23.63022	52.42460	75.22245	79.33590	76.34847	56.97545	39.41793
VIB. ENERGY (%)						.0022218	1.392032	23.65907	45.05746
NEW ELECTRON (%)									0.
MAX.ELECT HEAT (%)									0.
ANHAR. COOLING (%)								3.315E-5	.0022512
NET FAST HEAT (%)	100	100	100	100	100	100	99.06926	76.68920	53.58515

RATE COEFFICIENTS (m3/s) FOR INDIVIDUAL PROCESSES

E/N(Td)		.005	.01	.03	.1	.3	1	2	5	10
PROCESS	EN. LOSS									
J= 0->2	.044	2.18E-20	2.84E-20	1.19E-19	1.71E-18	9.07E-18	3.82E-17	8.50E-17	2.21E-16	4.41E-16
J= 1->3	.073	2.37E-22	3.25E-22	2.09E-21	2.06E-19	5.74E-18	5.05E-17	1.32E-16	3.77E-16	7.63E-16
v= 0->1	.516						2.91E-22	4.73E-19	2.99E-17	1.65E-16
v= 0->2	1								4.31E-21	7.90E-19
v= 0->3	1.5								2.35E-23	2.59E-20
B3SIGMA	8.9									
B1SIGMA	11.3									
C3PI	11.75									
A3SIGMA	11.8									
C1PI	12.4									
D3PI	14									
H(n=2)	15									

RYDBERG SUM 15.2
IONIZATION 15.4
BALMER ALPHA 16.6

H2 Tables (continued).

TEMPORAL GROWTH SOLUTION:

E/N (Td = 1E-21 Vm2) 20 40 70 100 200 300 500 1000 2000
W(m/s) 28809 47910 87265 132240 289650 446860 725560 1258100 2121200
D/mu (eV) .76476 1.3505 2.3995 3.0243 4.5485 6.1429 9.6931 21.192 47.247
<E> (eV) .93348 1.8392 3.5343 4.5555 6.8719 9.2156 14.499 32.377 72.501
num/n (m3/s) 1.22E-13 1.47E-13 1.41E-13 1.33E-13 1.21E-13 1.18E-13 1.21E-13 1.40E-13 1.66E-13
nuu/n (m3/s) 7.6E-16 1.43E-15 2.55E-15 4.38E-15 1.28E-14 2.18E-14 3.75E-14 5.94E-14 8.98E-14
(EPL-EPG)(eV-m3/s) 5.64E-17 1.42E-16 2.75E-16 3.42E-16 4.70E-16 5.98E-16 9.19E-16 2.20E-15 5.18E-15
EN. BALANCE (%) .46 .09 .06 .06 .02 -.05 -.25 -.43 -.67

Spatial excitation and ionization coefficients (m2)
SUM VIB QUANT 7.11E-16 2.37E-15 3.65E-15 3.84E-15 3.53E-15 3.10E-15 2.41E-15 1.58E-15 1.11E-15
SUM TRIPLET 7.61E-23 1.28E-17 2.58E-16 6.86E-16 2.35E-15 3.82E-15 5.33E-15 5.24E-15 3.73E-15
MAX SUM VUV 1.77E-18 7.04E-17 2.78E-16 2.14E-15 5.83E-15 1.62E-14 4.24E-14 7.07E-14
alpha/n VIBRATION 2.47E-20 4.94E-20 4.18E-20 2.90E-20 1.22E-20 6.93E-21 3.33E-21 1.25E-21 5.21E-22
alpha/n DISSOCIATION 2.64E-27 2.67E-22 2.97E-21 5.22E-21 8.37E-21 9.13E-21 8.52E-21 6.18E-21 3.85E-21
alpha/n MAX VUV 3.70E-23 8.07E-22 2.11E-21 7.40E-21 1.30E-20 2.24E-20 3.37E-20-3.33E-20
alpha/n ION 4.42E-25 5.21E-23 2.56E-22 1.79E-21 3.93E-21 8.04E-21 1.39E-20 1.47E-20

FAST GAS HEATING CALCULATIONS [3]:

INPUT EN. (eV m3/s) 5.76E-16 1.92E-15 6.11E-15 1.32E-14 5.79E-14 1.34E-13 3.63E-13 1.26E-12 4.24E-12
ELASTIC HEAT (%) 9.785137 7.383636 4.498613 2.582426 .8109788 .4458518 .2533216 .1744694 .1220300
ROTATION. HEAT (%) 27.19176 19.56283 10.21643 5.389359 1.378344 .6129715 .2251012 .0601301 .0157950
VIB. ENERGY (%) 63.64973 63.72107 30.83624 14.97447 3.146439 1.191621 .3434670 .0647236 .0134504
NEW ELECTRON (%) 2.030E-5 .0026290 .0116557 .0614462 .1206928 .2330159 .4502053 .5325980
MAX ELECT HEAT (%) 5.813E-5 3.877172 29.78 41.56 44.47 40.43 31.95 19.06 8.432
ANHAR. COOLING (%) .0166173 .0388263 .0247430 .0128768 .0028726 .0010973 3.077E-4 5.161E-5 8.369E-6
NET FAST HEAT (%) 36.96034 30.78724 44.47112 49.51713 46.65930 41.49188 32.43333 19.29591 8.570203

RATE COEFFICIENTS (m3/s) FOR INDIVIDUAL PROCESSES
E/N(Td)
PROCESS EN. LOSS 20 40 70 100 200 300 500 1000 2000
J= 0->2 .044 9.21E-16 2.17E-15 3.57E-15 4.07E-15 4.54E-15 4.67E-15 4.64E-15 4.30E-15 3.82E-15
J= 1->3 .073 1.59E-15 3.83E-15 6.40E-15 7.31E-15 8.2E-15 8.44E-15 8.39E-15 7.77E-15 6.88E-15
v= 0->1 .56 6.76E-16 2.10E-15 3.11E-15 3.23E-15 2.93E-15 2.57E-15 2.01E-15 1.34E-15 9.78E-16
v= 0->2 1 1.57E-17 1.17E-16 2.36E-16 2.67E-16 2.62E-16 2.32E-16 1.77E-16 1.03E-16 5.64E-17
v= 0->3 1.5 1.21E-18 1.14E-17 2.32E-17 2.60E-17 2.49E-17 2.18E-17 1.64E-17 9.47E-18 5.15E-18
B3SIGMA 8.9 7.61E-23 1.08E-17 1.88E-16 4.6E-16 1.42E-15 2.23E-15 3.05E-15 2.99E-15 2.12E-15
B1SIGMA 11.3 1.40E-18 4.42E-17 1.47E-16 8.13E-16 1.88E-15 4.41E-15 9.73E-15 1.48E-14
C3PI 11.75 1.28E-18 4.19E-17 1.31E-16 5.18E-16 8.66E-16 1.21E-15 1.16E-15 8.24E-16
A3SIGMA 11.8 7.05E-19 2.58E-17 8.33E-17 3.44E-16 5.87E-16 8.43E-16 8.45E-16 6.07E-16
C1PI 12.4 3.50E-19 2.05E-17 8.69E-17 6.22E-16 1.53E-15 3.73E-15 8.54E-15 1.33E-14
D3PI 14 2.80E-20 2.45E-18 1.12E-17 7.02E-17 1.39E-16 2.24E-16 2.44E-16 1.83E-16
H(n=3) 15 1.09E-21 4.29E-19 3.88E-18 6.87E-17 2.37E-16 7.89E-16 2.35E-15 4.15E-15
RYDBERG SUM 15.2 2.71E-21 7.92E-19 6.69E-18 1.20E-16 4.28E-16 1.46E-15 4.27E-15 7.27E-15
IONI2ATION 15.4 2.12E-20 4.54E-18 3.38E-17 5.18E-16 1.76E-15 5.83E-15 1.75E-14 3.12E-14
BALMER ALPHA 16.6 2.71E-22 7.73E-20 5.86E-19 7.71E-18 2.29E-17 6.57E-17 1.76E-16 2.94E-16

SPATIAL GROWTH SOLUTION:
alpha/n ION (m2) 4.42E-25 5.21E-23 2.49E-22 1.63E-21 3.5E-21 6.95E-21 1.28E-20 1.69E-20

CONVECTIVE VELOCITY (m/s)	131100	278210	418050	672790	1148400	1807000
alpha/n DISSOCIATION (m2)	5.15E-21	8.13E-21	8.86E-21	8.62E-21	6.76E-21	4.65E-21
alpha/n MAX VUV (m2)	1.82E-21	5.3E-21	8.3E-21	1.31E-20	1.9E-20	2.20E-20

[1] S. J. Buckman and A. V. Phelps, J. Chem. Phys. 82, 4999 (1985).

[2] See JILA Information Center Report 14, October 1975 by P. E. Luft for details of BACKPRO calculation procedures.

[3] For a discussion of gas heating in a molecular gas, i.e., N2, see A. V. Phelps and L. C. Pitchford, Phys. Rev. 31, 2932 (1985).

OXYGEN ELECTRON TRANSPORT AND REACTION COEFFICIENTS

Data from JILA Information Center Report No. 28 by A. V. Phelps. September 1, 1985. Refer to S. J. Lawton and A. V. Phelps, J. Chem. Phys. 69, 1055 (1978) for discussions of sources of cross section data, the Boltzmann calculation leading to these data, and the tests of these cross sections and transport coefficients against swarm experiment.

The cross sections tabulated in Report 28 are available through the JILA Web site at http://jilawww.colorado.edu under the Atomic and Molecular Physics Program.

The number of figures shown in the table is that of the computer output as modified by intervening spreadsheets, etc. The accuracy of the Boltzamnn calculation is measured by the energy balances, but the final accuracy is measured by the agreement with experiment as cited in Lawton and Phelps, i.e., roughly 5%.

Table II. Transport and reaction coefficients for electrons in O2 at 300 K. Calculated using two-term approximation using the current modifications of BACKPRO, but with no exponential growth of electron density. The three-body attachment was calculated for an O2 density of 1 molecule/m . lE-21 = 10^21. 1 Td = 10E-21 Vm^2.

E/N (Td)	5	8	10	15	25	40	80	100	120	150	250
W (m/s)	26948	29122	32647	43502	63447	91891	157040	184340	208790	241350	322380
D/mu (eV)	.5186	.9691	1.2014	1.5654	2.0185	2.4035	3.0762	3.373	3.662	4.087	5.551
<E> (eV)	.7294	1.3985	1.7087	2.1944	2.7194	3.1719	3.973	4.333	4.694	5.2402	7.184
num/n (m^3/s)	3.26E-14	4.83E-14	5.39E-14	6.06E-14	6.93E-14	7.66E-14	8.96E-14	9.54E-14	1.01E-13	1.09E-13	1.36E-13
nuu/n (m^3/s)	2.73E-16	2.47E-16	2.78E-16	4.24E-16	7.96E-16	1.55E-15	4.12E-15	5.51E-15	6.89E-15	8.918-15	1.46E-14
(EPL-EPG) (eV-m3/s)	1.23E-18	2.82E-18	3.60E-18	4.93E-18	6.61E-18	8.39E-18	1.23E-17	1.44E-17	1.67E-17	2.05E-17	3.59E-17
EN. BALANCE (%)*	.32	.22	.23	.4	.38	.35	.44	.36	.31	.43	.34
SUM VIB QUANT(m^3/s)	5.33E-16	4.17E-16	3.90E-16	5.10E-16	7.42E-16	1.23E-15	2.51E-15	3.03E-15	3.50E-15	4.08E-15	5.17E-15
SUM TO B1SIG(m^3/s)	4.42E-18	2.46E-17	4.24E-17	9.64E-17	2.48E-16	5.58E-16	1.74E-15	2.48E-15	3.29E-15	4.57E-15	9.02E-15
SUM DISSOC.(m^3/s)	1.69E-21	1.43E-19	5.70E-19	3.26E-18	1.89E-17	1.02E-16	7.57E-16	1.27E-15	1.87E-15	2.89E-15	6.76E-15
alpha/n VIB. (m^2)	1.98E-20	1.43E-20	1.19E-20	1.17E-20	1.17E-20	1.34E-20	1.60E-20	1.65E-20	1.68E-20	1.69E-20	1.60E-20
alpha/nB1SIGMA(m^2)	1.64E-22	8.45E-22	1.30E-21	2.228-21	3.90E-21	6.07E-21	1.11E-20	1.35E-20	1.57E-20	1.89E-20	2.80E-20
alpha/n DISSOC(m^2)	6.26E-26	4.92E-24	1.74E-23	7.50E-23	2.97E-22	1.11E-21	4.82E-21	6.89E-21	8.97E-21	1.20E-20	

2.10E-20
alpha/n NET IONIZ. -1.7E-21 -1.4E-19 -5.7E-19 -3.1E-18 -1.1E-17 -2.2E-17 -3.3E-17 -2.7E-17 -7.3E-18 5.64E-17 7.10E-16
(m^2)

RATE COEFFICIENTS (m3/s) FOR INDIVIDUAL PROCESSES

E/N(Td)   5   8   10   15   25   40   80   100   120   150   250
PROCESS and EN. LOSS (eV)
3-BODY ATTACH./n   1.05E-42 5.26E-43 3.80E-43 2.85E-43 1.92E-43 1.51E-43 1.30E-43 1.14E-43 1.02E-43 1.36E-43 3.76E-44
2-BODY ATTACH.   1.69E-21 1.43E-19 5.69E-19 3.14E-18 1.13E-17 2.21E-17 3.76E-17 4.18E-17 4.47E-17 4.74E-17 4.91E-17
ROTATION   .02   2.39E-17 1.86E-17 1.63E-11 1.70E-17 1.25E-17 1.03E-17 1.16E-17 1.04E-17 9.33E-18 5.97E-18 4.46E-18
v= 0-1   .19   3.38E-16 1.98E-16 1.74E-16 2.75E-16 3.08E-16 4.68E-16 8.56E-16 1.01E-15 1.14E-15 1.33E-15 1.62E-15
v= 0-2   .38   7.15E-17 7.28E-17 7.13E-17 8.05E-17 1.30E-16 2.02E-16 3.75E-16 4.44E-16 5.05E-16 5.91E-16 7.14E-16
v= 0-3   .57   1.31E-17 1.79E-17 1.77E-17 1.64E-17 3.62E-17 7.18E-17 1.72E-16 2.15E-16 2.54E-16 2.97E-16 4.02E-16
v= 0-4   .75   3.18E-18 4.94E-18 5.01E-18 6.25E-18 1.62E-17 3.69E-17 9.74E-17 1.23E-16 1.46E-16 1.71E-16 2.30E-16
a 1DELTA   .977   2.41E-17 1.05E-16 1.58E-16 2.59E-16 3.81E-16 4.85E-16 6.40E-16 6.94E-16 7.40E-16 7.96E-16 9.12E-16
b 1SIGMA   1.627   4.40E-18 2.30E-17 3.64E-17 6.17E-17 9.07E-17 1.14E-16 1.49E-16 1.61E-16 1.72E-16 1.85E-16 2.14E-16
4.5 LOSS   4.5   2.38E-20 1.44E-18 5.13E-18 2.49E-17 8.47E-17 1.72E-16 3.40E-16 4.02E-16 4.53E-16 5.12E-16 6.00E-16
6 LOSS   6   3.05E-22 1.27E-19 8.50E-19 9.65E-18 6.46E-17 1.91E-16 5.31E-16 6.89E-16 8.36E-16 1.03E-15 1.50E-15
8.4 LOSS   8.4   8.62E-24 5.52E-22 1.20E-19 7.59E-18 8.02E-17 7.19E-16 1.23E-15 1.82E-15 2.83E-15 6.67E-15
9.97 LOSS 10   2.42E-25 2.41E-22 1.36E-20 6.25E-19 1.59E-18 3.17E-18 6.86E-18 3.18E-17
IONIZATION 12.06   1.63E-20 4.10E-18 1.47E-17 3.74E-17 1.04E-16 7.59E-16
DIS. EXCIT.14.7   2.64E-20 1.32E-19 4.12E-19 1.39E-18 1.30E-17

*See S. Yoshida, A. V. Phelps and L. C. Pitchford, Phys. Rev. A 27, 2858 (1983) for the calculation of the contribution of ionization to the energy balance. The calculation for attachment is simllar. In the energy balance attachment results in a term equal to the negative of average electron energy times the attachment rate coefficient and a term equal to the average of the energy times the energy dependent attachment frequency.

AIR-ELECTRON TRANSPORT AND REACTION COEFFICIENTS
Table corrected 5/7/98
Electron transport and reactions in dry air:
The first nine (9) columns can be scaled to any air density n provided that the energy relaxation frequency nuu is small compared to the three-body attachment frequency nua3. The condition fails at low E/n as one approaches atmospheric density at sea level.
The last four columns are the result of scaling to a nominal altitude of 80 km.

n = 4.00E+14 cm-3 at 80 km   recombination:
From calculations of 2/19/87   night time n+ = 4.00E+02 cm-3 at 80 km   (1/ne)dne/dt = 2.40E-02 s-1
by A. V. Phelps, JILA, U of Colorado and NIST   effective alph recomb. =6.00E-05 cm3s-1 at 80 km

E/n   W   Ek   <E>   num/m   nuu/n   ala3/n2   nua2/n   nui/n   netnui/n   nua   nui   netnui   nuu
Td   cm/s   eV   eV   cm3/s   cm3/s   cm5   cm3/s   cm3/s   cm3/s   s-1   s-1   s-1   s-1

1.00E-02 4.41E+04 2.53E-02 3.78E-02 3.99E-09
2.00E-02 8.55E+04 2.61E-02 3.87E-02 4.11E-09
5.00E-02 1.80E+05 3.14E-02 4.47E-02 4.90E-09 1.66E-11   6.65E+03
1.00E-01 2.49E+05 4.58E-02 6.12E-02 7.06E-09 1.26E-11 6.80E-37   2.71E-02   5.03E+03

2.00E-01 2.86E+05 8.10E-02 9.93E-02 1.23E-08 1.04E-11 6.90E-37 3.16E-02 4.16E+03
5.00E-01 4.06E+05 1.48E-01 1.66E-01 2.17E-08 1.67E-11 3.90E-37 2.53E-02 6.66E+03
1.00E+00 6.15E+05 2.05E-01 2.32E-01 2.86E-08 3.44E-11 1.97E-37 1.94E-02 1.37E+04

The calculations below used improved cross sections at high electron energies
1.00E+00 6.67E+05 1.94E-01 2.24E-01 2.64E-08 3.98E-11 1.93E-37 2.06E-02 1.59E+04
2.00E+00 9.76E+05 2.90E-01 2.49E-01 3.60E-08 7.39E-11 9.07E-38 1.42E-02 2.96E+04
5.00E+00 1.44E+06 6.08E-01 7.24E-01 6.13E-08 1.23E-10 2.89E-38 6.64E-03 4.93E+04
1.00E+01 2.05E+06 9.12E-01 9.35E-01 8.58E-08 2.31E-10 1.29E-38 4.24E-03 9.26E+04
2.00E+01 3.35E+06 1.13E+00 1.04E+00 1.05E-07 6.05E-10 6.40E-39 3.43E-03 2.42E+05
4.00E+01 5.82E+06 1.30E+00 1.14E+00 1.21E-07 1.83E-09 3.48E-39 3.24E-03 7.33E+05
5.00E+01 6.94E+06 1.37E+00 1.22E+00 1.27E-07 2.58E-09 2.04E-13 2.24E-15 -2E-13 81.6 0.896 -80.704
1.03E+06
7.00E+01 9.01E+06 1.61E+00 1.64E+00 1.37E-07 3.97E-09 1.24E-12 9.49E-14 -1.1E-12 495.2 37.96 -457.24
1.59E+06
8.50E+01 1.05E+07 1.87E+00 2.10E+00 1.43E-07 4.82E-09 2.42E-12 5.18E-13 -1.9E-12 968 207.2 -760.8
1.93E+06
1.00E+02 1.19E+07 2.16E+00 2.60E+00 1.48E-07 5.58E-09 3.74E-12 1.81E-12 -1.9E-12 1496 723.2 -772.8
2.23E+06
1.10E+02 1.28E+07 2.36E+00 2.94E+00 1.51E-07 6.04E-09 4.54E-12 3.49E-12 -1E-12 1816 1396 -420
2.42E+06
1.20E+02 1.37E+07 2.56E+00 3.28E+00 1.54E-07 6.49E-09 5.30E-12 6.16E-12 8.6E-13 2120 2464 344
2.60E+06
1.50E+02 1.63E+07 3.13E+00 4.20E+00 1.62E-07 7.88E-09 7.07E-12 2.27E-11 1.56E-11 2828 9080 6252
3.15E+06
2.00E+02 2.04E+07 3.88E+00 5.35E+00 1.72E-07 1.06E-08 8.71E-12 9.43E-11 8.56E-11 3484 37720 34236
4.23E+06

Ek - characteristic electron energy
<E> - mean electron energy
num/n - momentum transfer collision frequency per molecule
nuu/n - energy exchange collision frequency per molecule
ala3/n2 - spatial three-body attachment coeffient normalized to square of density
nua2/n - two-body attachment frequency per molecule
nui/n - ionization frequency per molecule
netnui/n - net ionization frequency per molecule
nua - reciprocal electron lifetime for decay by attachment (no ionization) at 80 km
nui - reciprocal electron lifetime for growth by ionization (no attachment) at 80 km
netnui - net reciprocal electron lifetime for growth at 80 km
nuu - reciprocal lifetime for electron energy loss at 80 km

Calculations for dry and moist (1.5% H2O) air at 1 std. atmosphere and for selected electron excitation coefficients are available on request to avp@jila.colorado.edu.